THE NBS PROGRAM ON CORRIDOR FIRES

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Besides being the main means of evacuation of occupants, the conventional corridor in a multiple-occupancy building can also serve as the main route for smoke and flame spread during a fire. For this reason the behavior of fire in a corridor occupies a unique position in fire research. From both a research and a safety viewpoint the corridor problem has many facets, because of the variety of materials that can be used as corridor linings and the possible physical interactions throughout the development of a fire. Consequently corridor studies have been diversified in both content and emphasis. However, up to now all corridor studies have been primarily experimental programs, partly because of the inherent complexity of the interacting thermal and fluid flow phenomena in a dynamic corridor fire and partly because of lack of sufficient quantitative data.

The present NBS corridor fire program is designed to investigate the growth and spread of fire and smoke through a corridor when a fire is initiated in an adjoining room, simulating the condition that occurs when a fire starts in a room and its door to the corridor is open or fails. The study investigates both the contribution of the corridor interior finish materials on the wall, ceiling, and floor under the full-scale fire situation and the interaction of those surfaces with each other. With the role of floor coverings brought to the forefront by recent fires,[2] and in view of the fact that little study has been done on ceiling and floor interaction, researchers are focusing attention on floor coverings as well as on other variables in a corridor fire.

Because of the lack of precise understanding of the dynamics of the corridor fire, the obvious approach to the problem must still be by experimentation, supplemented by analysis of the experimental findings. Previous studies and dimensional analysis indicate that the absolute height of the corridor determines the mode of ceiling and floor interactions. Not wishing to alter drastically the ceiling and floor interaction at this time, we chose a full-scale physical model.

The first objective of the program was development of fire safety criteria for controlling materials to be used in a corridor. The criteria were to be based on the thermophysical properties of wall, ceiling, and floor linings, properly weighted to allow for their relative positions. The approach to this first objective was based on the assumption that we could develop a model from energy considerations – a model that would properly reflect such things as the properties of the lining materials, the aspect ratio of the corridor, and the energy balance within the system. The corridor program was designed to develop that model. The model was envisioned in two parts: first, a gross model, to determine the changes in energy levels caused by the various materials, as a function of their properties and location; and, second, a more exact model, to determine the amount of energy delivered to any particular surface as a result of the over-all interchanges of radiant and convective energy within the corridor.

The second objective of the program is to study and describe the fire propagation characteristics in a corridor. If we define the fire hazard in the full-scale model in terms of energy and flame spread, then we have a basis for evaluating the many small-scale tests now being proposed for rating wall, ceiling, and floor coverings. These tests will be used for the control of materials in buildings; and development of a scale of relative fire hazard is critical to this evaluation. Attempts will also be made to present the experimental data on full-scale flame propagation in appropriate nondimensional terms for possible similarity scaling comparison with small-scale tests conducted at the NBS.

The Test Facility

To develop the energy model, the corridor is equipped with forced air draft capability and instrumentation to study the corridor fire as a function of air flow and heat transfer by radiation, convection, and conduction.

The authors wish to acknowledge their indebtedness to Mr. J. S. Steel of the NBS Fire Research Section, Building Research Division, for his contribution to the extensive instrumentation work.

Funds for this research work were provided by the Department of Health, Education and Welfare, through FECA, by the Veterans Administration, and from NBS appropriations.

The Carpet Research Institute provided the carpets used in this program.

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[2] Albert B. Sears, Jr., "Nursing Home Fire, Marietta, Ohio," FIRE JOURNAL, Vol. 64, No. 3 (May 1970), p. 5 (also available as Reprint FJ70–13; single-copy price, $1.00).

vol. 67, no. 3

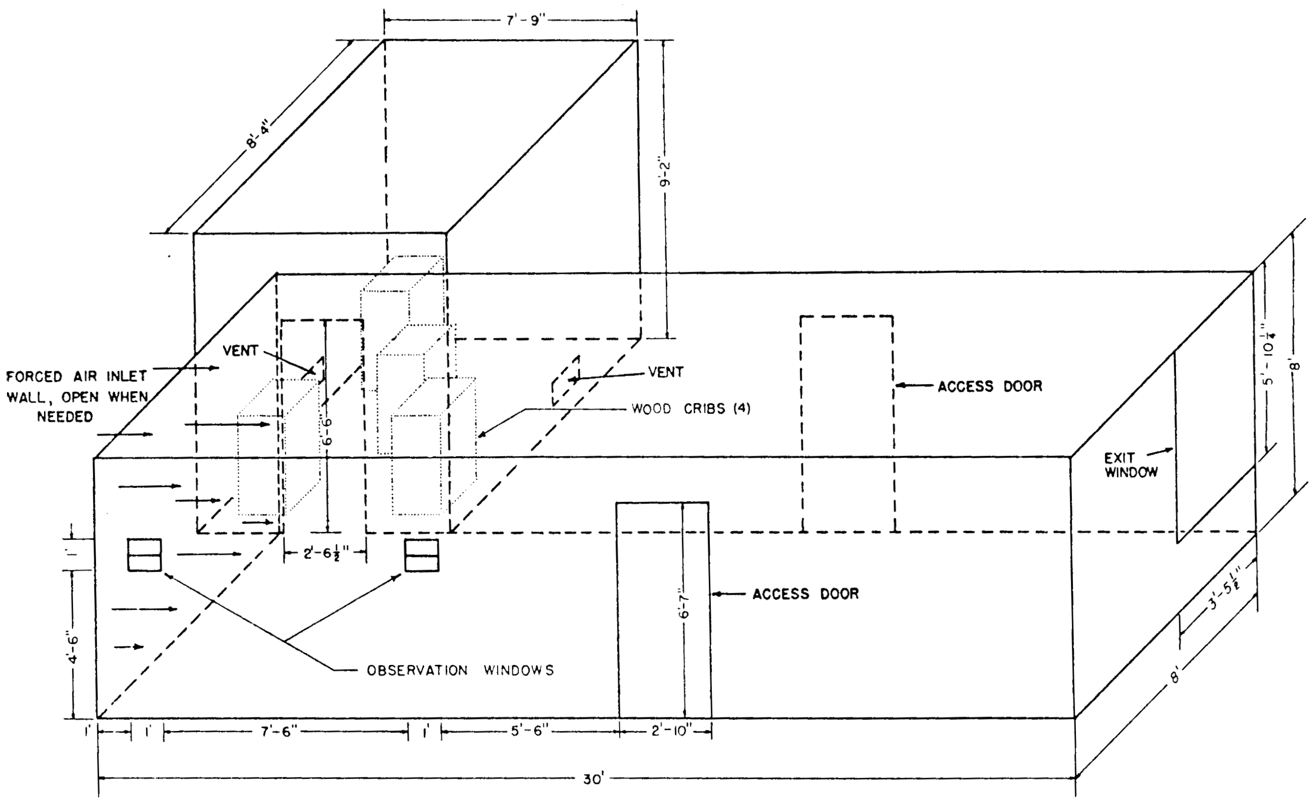

Figure 1. Corridor Facility, with Dimensions

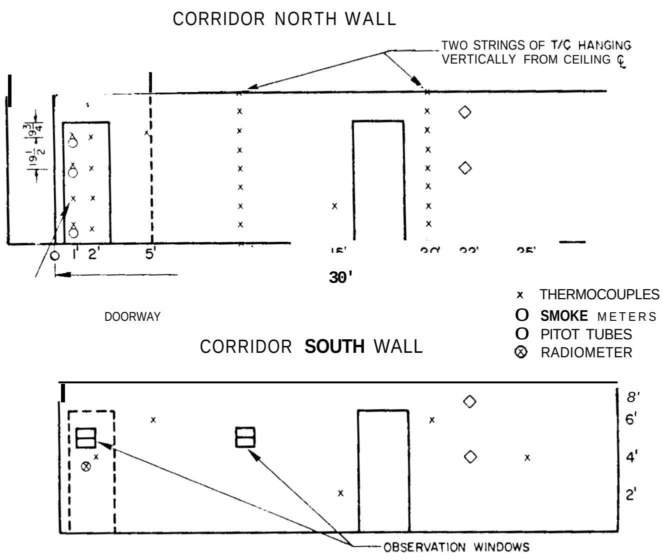

Figure 2. Corridor Wall Sensor Locations

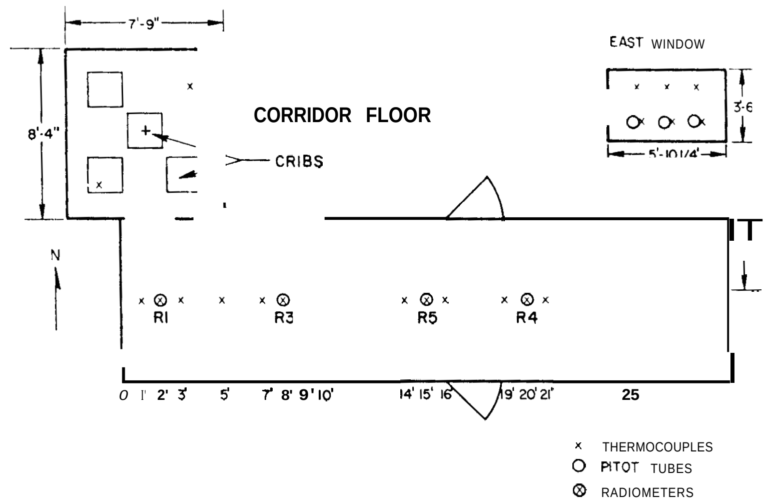

Figure 3. Corridor Floor Sensor Locations

Figure 1 shows the corridor facility used in these experiments. The corridor is 30 feet long by 8 feet wide by 8 feet high, with provisions having been made to increase the width up to 12 feet and the height to 9 feet. The adjustable width and height will permit examination of several aspect ratios. A doorway 6½ feet high by 30½ inches wide located in the side wall at the rear end of the corridor connects the corridor to an eight-foot-square-by-nine-foot-high "burn room" where all the fires are initiated. Two 14-inch-by-6½-inch vents are located near floor level on opposite walls of the burn room, to simulate air ducts into a room. There are two access doors located at the approximate center of the corridor length. At the far end of the corridor there is an exit window 70¼ inches high by 41½ inches wide.

The corridor is situated in a brick building, with only the exit window connected to the outside. Air-conditioning equipment provides air flow for material conditioning and for controlled draft whenever forced **flow** is desired. The unit is capable of supplying a maximum air flow of 7,500 cubic feet per minute at 75°F with the relative humidity at 30 per cent. The basic construction of the corridor walls and ceiling is %-inch-thick Type X gypsumboard attached to a superstructure of metal studs 16 inches on centers. Between the studs are two-inch-thick glass-fiber batts for insulation. When it is not covered with some other material under test the exposed gypsumboard surface is painted with a fire-retardant paint. The floor is of brick laid on sand. **A** wood frame placed on the perimeter of the floor is used as a base for a tacking strip for laying carpet. **A** plywood or asbestos cement subfloor is placed over the brick when desired. The ceiling and flooring materials to be tested are then attached, respectively, to the gypsumboard ceiling and to the subfloor. Table **2** shows some of the ceiling and floor materials used in the experiments.

Measurements were made of temperature, velocity, total radiation heat flux, the weight loss of burning combustibles, smoke density, continuous gas analysis, and batch gas sampling. Also, 16mm color motion picture coverage was provided by both stationary and roving cameras. Figures 2 and 3 show specific sensor locations in the corridor and the burn room.

Chromel-alumel thermocouples (0.020-inch-diameter wires) were placed at 65 locations in the corridor and the burn room, as Figures 2 and 3 show, Thermocouples on the material surfaces provide information on surface temperature and can also be used for simplified heat conduction calculations. Six thermocouples placed at the exhaust window and eight thermocouples at the burn room door provide temperature profiles for convective energy transport calculations. Two vertical strings with eight thermocouples placed one foot apart hang from the corridor ceiling center line at the 10- and 20-foot stations, measured from the end of the corridor near the burn room. These thermocouples provide temperature profiles as well as information on convective heat transfer. Thermocouples are placed along the corridor floor center line spaced eight feet apart on floor-lining surfaces and one inch above the floor, to provide floor surface temperatures and flame spread information. Thermocouples along the corridor ceiling surface center line give information on heat conduction and flame spread and are used to calculate approximate ceiling radiation levels.

High-temperature stainless steel pitot tubes were mounted horizontally at the exhaust window and at the burn room door, to provide horizontal velocity profiles and information on convective heat transfer. The pressure differences were measured by using variable reluctance transducers with a full-scale range of one-inch water pressure.

Four wood cribs, each weighing approximately **43** pounds, represented the fire load in the burn room. The weight loss of a burning crib **was** measured by a 500-pound-capacity strain gage load cell supporting a weighing platform. Moving the load cell to cribs located at different positions in the burn room demonstrated that the rate of weight loss of each crib did not vary significantly with respect to locations in the bum room. If all the cribs for a given test have the same weight loss history as the centrally located crib, the total mass burning rate can be obtained.

A maximum of five radiometers were used to measure reduction and heat flux, one located at the corridor south wall facing the bum room door, four located along the corridor floor center line at intervals beginning with the one-foot-eight-inch station from the corridor west end. They were positioned facing up toward the ceiling, to measure the radiation exposure at the floor

Smoke measurements were made by gas-sampling and light obscuration. Two gas-sampling techniques were used to assess the corridor atmosphere during the tests: (1) continuous measurements of oxygen, carbon monoxide, and carbon dioxide concentrations and (2) grab samples collected in pre-evacuated two-liter flasks for laboratory analysis. The sampling for continuous gas analysis was made 22 feet down the corridor and six inches below the ceiling center line. The grab samples were taken 22 feet down the corridor, at eight feet, seven feet, and four feet from the floor. An effort was macle to collect the gas samples just before full flame involvement occurred or during the worst part of the fire. Laboratory analysis of the grab samples was done by using infrared absorption. In some cases mass spectrometric analyses were also performed.

Obscuration measurements by light beam and photo cell setups were made at three locations in the corridor – two horizontal measurements 22 feet down the corridor at seven-foot and four-foot heights and one vertical measurement at the exit end of the corridor.

Summary of the Phase 1 Experiments

In all the tests conducted so far, the corridor walls were lined with gypsumboard and the corridor cross-section was eight feet by eight feet. Cribs made up of fir sticks measuring 1%by 1%inches in cross-section **and** 15%inches in length were used as the fire energy source in the burn room. Before each test the cribs were dried to a moisture content of approximately 10 per cent or less. The fire load was standardized to four cribs, each weighing approximately **43** pounds, yielding

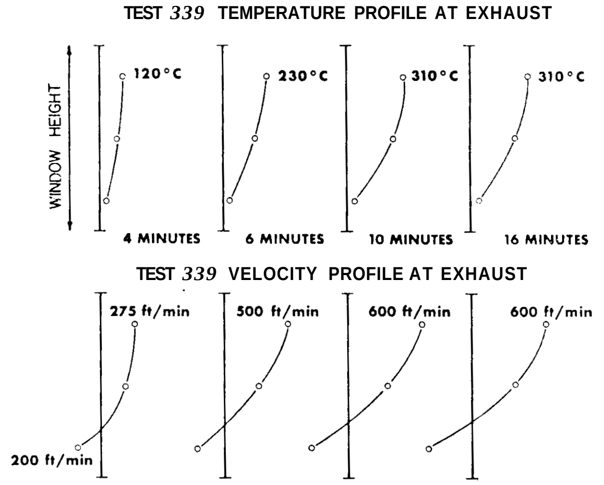

Figure 4. Temperature and Velocity Profiles at Exit Window

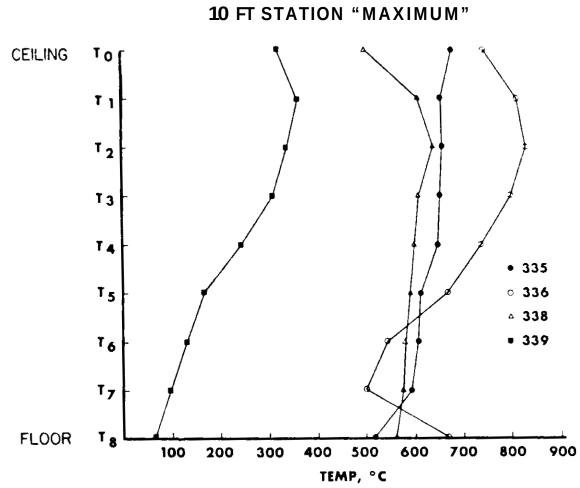

Figure 7. Temperature Profile inside Corridor

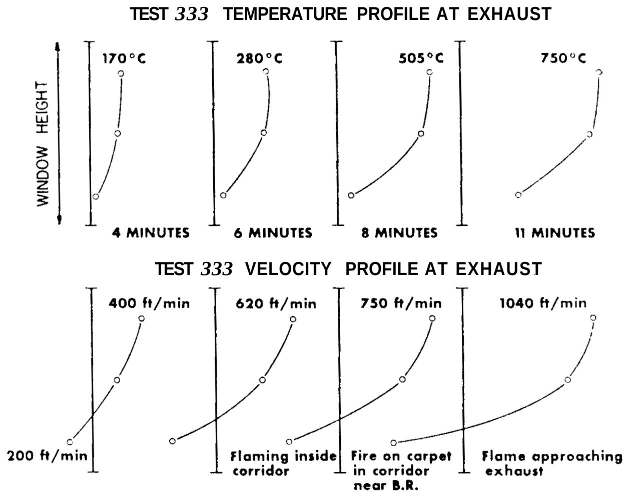

Figure 5. Temperature and Velocity Profiles at Exit Window

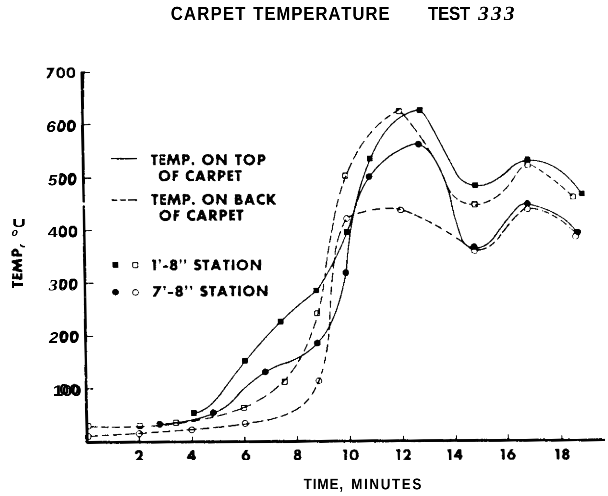

Figure 8. Carpet Temperatures

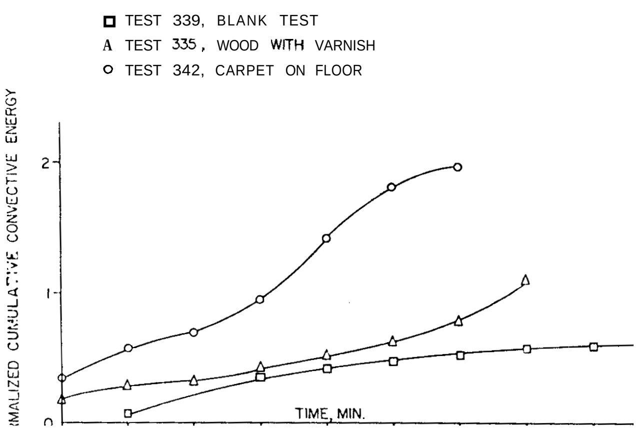

Figure 6. Ratio of Exit Window to Burn Room Convective Energy

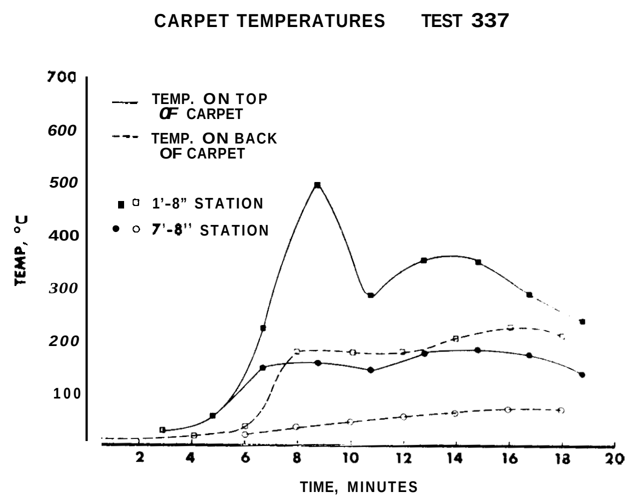

Figure 9. Carpet Temperatures

Table 1. hlaterial Description

Material	*Flame Spread* (by ASTM E162)	*Description*
Corridor Walls		
Gypsum wallboard	13	E-incli Type X gypsum wallboartl, painted with intumescent white paint
Corridor Ceiling		
Gypsum wallboard	13	⅝-inch Type X gypsum wallboard, painted with intumescent white paint
Sugar cane pulp board	74(1) 222(2)	(1) treated side (2) untreated side
Particle board	102	Pressed wood with resin
"Ceramaguard" board		Ceramic ceiling material with tunnel flame spread rating under 25
Corritlor Floor		
Brick	0	Brick set in sand as basic subfloor
Carpet So. 1 and pad	145 w/o pad 150 with pad	Brown 100% acrylic carpet, ¼-inch low pile, 10–12 oz./sq. yd.; pad, "rubberized" surfaces with jute filler 0.46-inch thick
Carpet No. 3 and pad	445 with pad	Blue acrylic carpet 1/10-5/16-inch low pile, 32 oz./sq. yd.; pad same as above
Carpet No. 9	284 integrated pad	Gold nylon, ⅛-inch low pile, pile weight 20 oz./1 yd.²
Carpet No. 10	64 w/o pad 119 with pad	100% wool, 7/32-inch low pile, pile weight 38 oz./yd.²; pad same as above
Oak floor, varnished	109	Tongue-and-groove hard oak floor with two coats spar varnish; laid over ½-inch-thick plywood
Vinyl asbestos tile	23	Asbestos tile applied to plywood floor with black tile adhesive
Burn Room		
Refractory coating		½-inch high-temperature cement sprayed to basic cement-block walls and cement ceiling

a fire load of 2.7 pounds per square foot of burn room floor area. Exploratory experimental results indicated that for the particular corridor configuration a fire loading of three 43-pound cribs was probably marginal. No flame propagation on the ceiling was observed when three cribs or fewer were used in conjunction with a combustible particleboard corridor ceiling and 100-foot-per-minute forced draft in the corridor.

The corridor ceiling materials used were gypsumboard, fiberhoard, and particleboard. The flooring materials used were brick, carpet (with and without pads), vinyl asbestos tile, and varnished oak. Where flooring other than brick was used an asbestos cementboard subfloor, covered with the flooring material to be studied, extended eight feet into the burn room. Table 2 summarizes the tests, showing the corritlor material linings and the observations on flame propagation. Table 1 describes the materials used.

The draft conditions in the tests were produced by either natural convection or a forced draft of approximately 100 fpm. The forced draft used is within the range of air flow encountered in corridors serving as return air plenums in enclosed buildings.

The Results

As the NBS corridor fire program is still in an early stage of development and as this article is intended as the first of a series of reports on the program, only typical data are presented. In this series of studies Test 339, with gypsumboard walls and ceiling and brick floor, is intended as the reference run for comparison with the other tests in which the corridor contained combustible materials. In Test 339 no flames left the burn room. During the complete 20-minute test run only hot air, smoke, and gases moved down the corridor. The energy transport maximized at seven minutes and stayed level until the crib fire started to decrease. The hot air that flowed down the corridor reached a maximum temperature of 310°C (590°F) and a velocity of 600 feet per minute at the exit window, and the temperature and the velocity stayed constant until the crib fire started to decrease (see Figure 4).

In Test 333 (with gypsumboard ceiling and Sample No. 1 rug and pad), just before flaming in the corridor, at six minutes, the maximum exit window temperature and the velocity were, respectively, 280°C and 620 feet per niinute (see Figure 5). When the flame reached the exit window, at 11 minutes, due to flame spread on the carpet, the exit window temperature and the velocity climbed sharply, to 750°C and 1,040 feet per minute, respectively.

Our present work has been devoted to determining, by measuring the convective energy transport at the corridor exit and the energy transport at the corridor

Table 2. Summary **of Corridor Flame Observations**

Test No.	*Corridor* ***Test*** *Conditions* *Ceiling*	*Floor*	*Wall*	***Airflow***	*Observations*	*Flame* Traverse Time* (hlin.: Sec.)
329	Particle board	Brick	Painted gypsum board	6200 cfm	Flame reached end of corridor along ceiling at 12:00	***
330	Particle board	Sainple No. 1 rug and pad	Painted gypsum board	*0*	Ceiling ignited at 2:30; carpet ignited at 2:35; flame reached end of corridor at 2:55	0:25
332	Particle board	Brick	Painted gypsum board	0	Ceiling flame reached end of corridor at 9:20; carpet sample at 1'8"; station ignited at 10:15	1:30
333	Painted gypsum board	Sample No. 1 rug and pad	Painted gypsum board	0	Flaming in corridor air at 6:00; flaming on carpet at 7:45	5:00
334	Particle board	Sample No. 1 rug and pad	Painted gypsum board	6550 cfm	Heavy smoke in corritlor at 7:00; flaming in corridor reached end of corridor at 9:20	***
335	Painted gypsum hoard	Varnished oak	Painted gypsum board		Corridor air ignited at 5:00; flame reached end of corridor at 8:50	3:50
336	Painted gypsum board	Vinyl asbestos tile	Fainted gypsum board	0	Flaming on floor outside burn room door at 6:30; flame on floor spread to 10-ft. station at 8:40	**NA**
337	Painted gypsum board	Sample No. 1 rug w/o pad	Painted gypsum board	0	Carpet near burn room door ignited at 7:00; spontaneous ignition **of** carpet up to 15-ft. station; fire on carpet went out at 8:00	**NA**
338	Particle hoard	Sample No. 1 rug w/o pad	Painted gypsum board	0	Flaming in corridor air at 5:40; flaming reached end of corridor at 7:00	1:20
339	Painted gypsum board	Brick	Painted gypsum board	0	No fire in corridor; slight charring of gypsum paper near burn room; air and wall temperatures reached steady state at approximately 7 minutes	**NA**
340	"Cerama-guard" board	Sample No. 3 rug and pad	"Cerama-guard" board	*0*	Flames on carpet near burn room door at 5:00; flame reached end of corridor at 7:05	2:05
341	Painted gypsum board	Sample No. 10 (wool) w/pad	Painted gypsum hoard	0	Flames on carpet beyond burn room door at 6:15; carpet fire out at 7:34; carpet reignited at 8:00; flame reached end of corritlor at 9:30	1:30
342	Painted gypsum board	Sample No. 9 (nylon) w/ integral pad	Painted gypsnm board	0	Carpet on fire at 4:45; flaming in corridor at 4:50; flame reached end of corridor at 6:20	1:30
343	Painted** gypsum hoard	Sample No. 10 w/o pad	Painted** gypsum board	*0*	Carpet ignited at 4:30; flaming on corridor at 5:00; flame reached end of corridor at 5:55	0:55

* Flame traverse time: time for flame to travel the whole length of the corridor (beginning of corridor involvement to flame reached end of corridor).

** Not fire-retardant paint

*** Corridor flaming initiation not recorded

Table 3. Time Flame Reached End of Corridor,* Min.:Sec.

		Floor Material								
Ceiling	*Draft*	*Brick*	*Carpet No. 1 w/o pad*	*Carpet No. 1 w/pad*	*Vinyl asbestos*	*Carpet No. 3 w/pad*	*Oak w/varnish*	*Carpet No. 10 w/pad*	*Corpet No. 10 w/o pad*†	*Carpet No. 9 w/integrated pad*
Particle Board	Natural	10:15 (332)**	7:00 (338)	2:55 (330)						
Particle Board	100 fpm	12:00 (329)		9:20 (334)						
Gypsum Board	Natural	(339)	(337)	12:40 (333)	(336)		8:50 (335)			
"Cerama Guard" Board	Natural					7:05 (340)				
Gypsum Board	Natural							9:30 (341)		
Gypsum Board	Natural								5:55 (343)	
Gypsum Board	Natural									6:20 (342)

* Time elapsed from ignition to flame reaching end of corridor
** Number in parenthesis denotes test number
† Corridor wall and ceiling painted with rubber-base paint instead of fire-retardant paint

Table **4.** Sample Gravimetric Smoke Data

Test	*Time (Min.)*	*Concentration (mg/l)*
339	5.0 – 6.0	0.2
	9	0.6
	14	0.2
	19	0.1
340	5.0	0.3
	7.0 – 8.0*	11.5
	8.0 – 9.0**	6.0

* Flame reached end of corridor
** Extinguishment

inlet, the incremental energy introduced by the various materials placed in the corridor. For each experiment the normalized cumulative energy (a ratio formed by dividing the cumulative convective energy output by the cumulative energy input) is compared with a standard blank test with gypsum ceiling and walls and a brick floor (see Figure 6). We believe that the normalized incremental or excess energy above the blank test serves as a good indication of the corridor fire involvement. We are now evaluating this information for correlation with material properties. Figure 6 shows typical normalized cumulative energy ratio plots, giving for two tests the extent of the flooring contribution in terms of the incremental energy ratios above the blank test. These incremental energies in our view represent quantitatively one measure of the relative fire hazard presented by the floor covering. Later experiments will (1) determine the critical level of normalized convective energy ratio to initiate corridor ignition and (2) evaluate the relative fire hazard of different corridor configurations according to the incremental energy. Therefore the incremental energy can serve as a means of defining the fire hazard of the assembly of materials in the corridor. A scale of relative fire hazard should include the following considerations:

1. The time for flame spread to the whole length of a corridor.
2. The incremental energy output.
3. The critical level of cumulative energy to initiate corridor fire.
4. The output of smoke and gas.

Figure 7 shows for various tests a comparison plot of the maximum temperatures for the vertical string of thermocouples in the middle of the corridor. Temperature profiles like these will help to develop analytical flame propagation models.

Table 3 summarizes the time for flame to reach the end of the corridor in various tests. We see that the shortest time, 2:55 minutes, was registered for Test 330, with the particleboard ceiling and Carpet No. 1 with pad. In Tests 336 and 337 flame propagated only part of the way down the corridor. This explains the infinite entries.

Figures 8 and 9 are front- and back-surface temperature plots for the carpet in Tests 333 and 337. In Test 333 there was a pad beneath the carpet; in Test 337, no pad. One can clearly see that in Test 333 the back side of the carpet was considerably hotter, probably because of the added insulation between the carpet and the floor. As a result the carpet flame propagated only part of the way down the corridor in Test 337, whereas in Test 333 the carpet flame traveled the whole length of the corridor.

Table 4 presents gravimetric smoke data collected for Tests 339 and 340. The particles gathered consisted of particulates and condensable gases, excluding moistures and vapors condensable below 150°C. The data clearly indicate that Carpet No. 3 contributes significantly to the over-all smoke level produced by corridor fire, as compared to Test 339, where only wood cribs were burning.

Qualitative Observations

The preliminary nature of this report precludes any general summary of findings. However, from the limited tests conducted the following qualitative observations may be made:

Flames propagated all the way down a corridor from fire in an adjoining room with 2.7 pounds per square foot burn room fire load with the following corridor configurations:

Ceiling	*Floor*	*Draft*
Particleboard	Carpet No. 1 with pad	Natural
Particleboard	Carpet No. 1 with pad	100 fpm
Particlehoard	Brick	Natural
Particleboard	Brick	100 fpm
Particleboard	Carpet No. 1 without pad	Natural
Gypsumboard	Carpet No. 1 with pad	Natural
Gypsumhoard	Varnished oak	Natural
"Cerama Guard"	Carpet No. 3 with pad	Natural
Gypsumboard	Carpet No. 10 with pad	Natural
Gypsumboard	Carpet No. 9 with integrated rubber backing	Natural
Gypsumboard*	Carpet No. 10 without pad	Natural

* Rubber-base paint

Flames did not propagate all the way down a corridor from fire in an adjoining room with a 2.7 pounds per square foot burn room fire load with the following corridor configurations:

Ceiling	*Floor*	*Draft*
Gypsumhoard	Carpet No. 1 without pad	Natural
Gypsumhoard	Vinyl asbestos tiles	Natural
Gypsumboard	Brick	Natural

Table 3 summarizes the "flame reached end of corridor time" for the test configurations studied. The shortest time – 2:55 minutes – was recorded for Test 330, with particleboard ceiling, Carpet No. 1 with pad on the floor, and natural draft. The longest time, 12:40 minutes, was recorded for Test 333, with gypsumboard ceiling, Sample No, 1 carpet with pad, and natural draft.

Drawing on the limited comparisons between Tests 330 and 334, one may conclude that, as compared to a natural convection fire, added "forced ventilation" in the corridor tends to delay corridor involvement, due to faster energy convection out the exit window. However, when fire does propagate and involve the corridor interior, added "forced ventilation" has the opposite effect, increasing fire intensity by "fanning."

Comparing Tests 333 and 337, one may conclude that the pad beneath the carpet plays an important role in carpet surface flame spread. The added insulation from the pad beneath the carpet promoted heat buildup, so that heat energy necessary to sustain carpet burning was retained.

The corridor fire program is being continued with additional experiments. In the future we shall attempt to analyze critical cumulative energy input and local radiation and convective energy transfers. So far, detailed energy calculations indicate that the ranking of the various floor coverings by incremental energy input is not only feasible but also informative. A follow-up report on the gross energy balance model together with detailed data is currently being prepared. In addition, we are preparing separately a report on the results of the smoke and gas analyses for the experiments conducted so far.

The heat transfer measurements in the corridor and other small-scale studies indicate that ceiling radiation is the dominant mode of energy transfer leading to flame propagation on the floor. As a result, mathematical modeling of flame propagation on carpets based on this assumption has been initiated.

Finally, small-scale carpet fire scaling studies are in progress. Analytical efforts have been directed toward correlating small- and large-scale results in nondimensional terms. This study and other local heat transfer mathematical modeling and scaling studies will be reported in subsequent papers. △

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